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Optical micro-metrology of structured surfaces micro-machined by jet-ECM

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Abstract

A procedure for statistical analysis and uncertainty evaluation is presented with regards to measurements of step height and surface texture. Measurements have been performed with a focus-variation microscope over jet electrochemical micro-machined surfaces. Traceability has been achieved using as reference contact measurements from a calibrated stylus instrument. A statistical analysis has been carried out and the method of least squares has been implemented to correct for systematic behaviours. The combined uncertainty has been evaluated accordingly and the expanded uncertainty has been finally calculated as the confidence interval of 95 %. Results show that agreement within single digit micrometre (dimensional measurements) and tenths of micrometre (surface parameters measurements) can be achieved with the proposed methodology.

Introduction

Measurements of step height and surface texture (Sa and Sq parameters) have been performed with a focus-variation microscope over two micro cavities (see figure 1), made of steel, which have been produced by additive manufacturing and successively structured by Jet Electro-Chemical Machining (Jet-ECM) [1]. Traceability has been achieved using as reference contact measurements of the same specimens from a calibrated stylus instrument [2]. Taking advantage of these measurements a procedure for statistical analysis and uncertainty evaluation has been determined, consistent with [3].

In a past work [4], Mattsson et al. already showed that agreement among surface roughness measuring instruments is limited mostly by: (a) Inaccuracies in repositioning the different instruments in the same measurement area. (b) The data set evaluation or post-processing.

The current investigation aims to establish a general method for analysing and correcting possible divergences among instruments which are due to systematic differences.

Pre-processing of measurements raw data

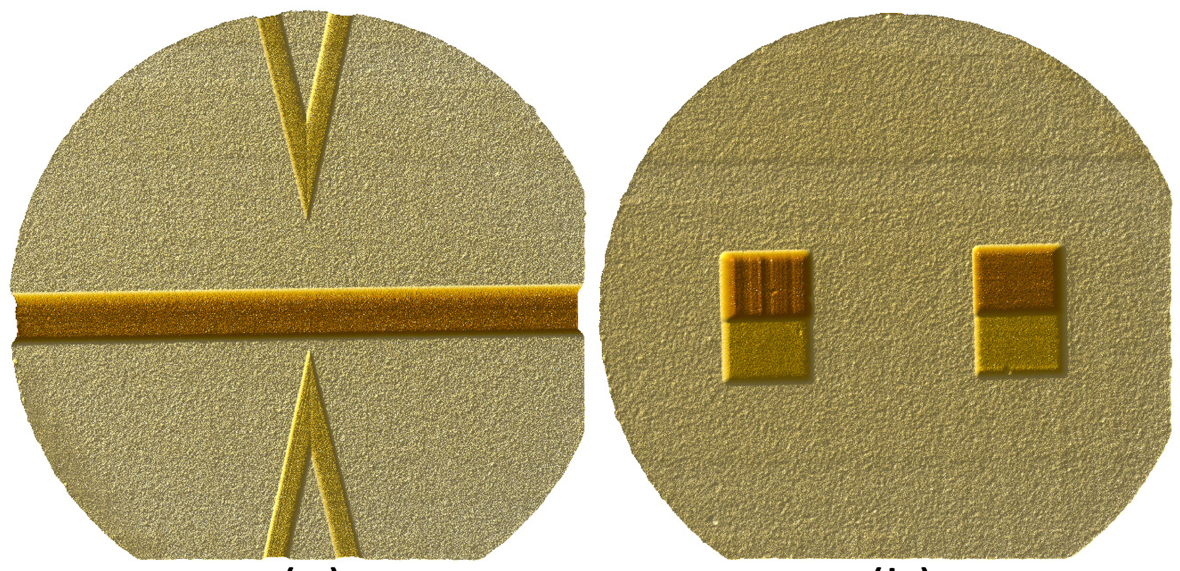
- Same image processing tool used to reduce software influences [5].
- Disturbances inspection → disturbances separated and discarded from the main data set.
- Incomplete image acquisitions → null pixels reconstructed by interpolation.
- No filters applied → waviness put in relation with its RMS value (*Rq* parameter) extracted by Fourier transform [6].

Statistical analysis and uncertainty evaluation

- Chauvenet's criterion applied for outliers detection.
- Correction of systematic differences → method of least squares implemented to identify regression models of systematic discrepancies between optical and contact measurements, i.e., the references. Descriptions and details of the techniques used can be found, e.g., in [7].
- In association with these model equations, combined uncertainty u evaluated (law of propagation of uncertainty) considering
  - accuracy of the stylus profilometer [2]
  - standard deviation of the coefficients in the regression models
  - the reproducibility (standard deviation of residuals)
  - precision of the image processing software [5].
- Expanded uncertainty calculated as the confidence interval of 95 % [3].

Results

- Two measurands (figure 2)
  - step height: twenty-five replications acquired → average value h = 162.3 µm;
  - surface texture: thirty replications acquired → average values Sa = 4.12 µm and Sq = 5.19 µm.
- Correction for systematic factors performed with respect to the time sequence of the replications.
- Correction for the accuracy achieved with respect to the contact measurements (figures 3 and 4).
- The expanded uncertainty evaluated (95 % confidence interval)
  - step height: U_h = 1.4 µm (max value);
  - Surface texture (Sa and Sq parameters): U_{Sa} = 0.44 µm and U_{Sq} = 0.46 µm (max values).



(a) (b)

Figure 1. Overview of the surface specimens. (a) Straight-lined grooves. (b) Sectioned surfaces at different heights.

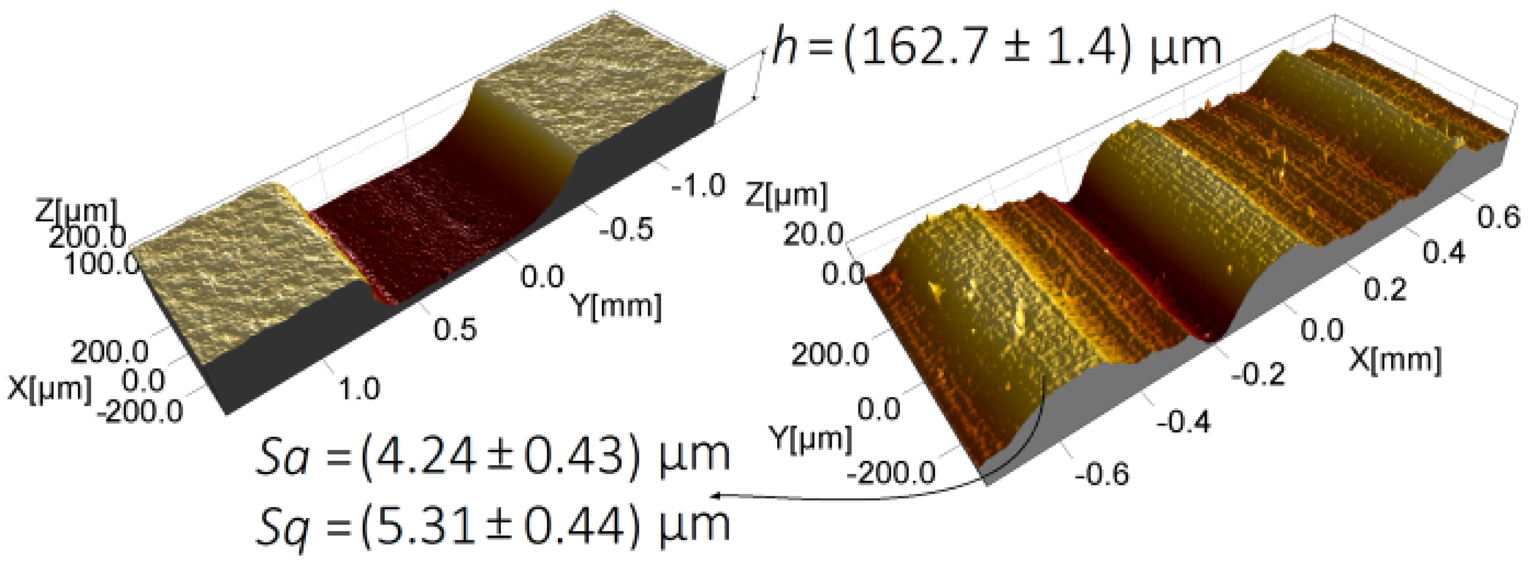


Figure 2. Illustration in 3-D of two examples of acquired surfaces.

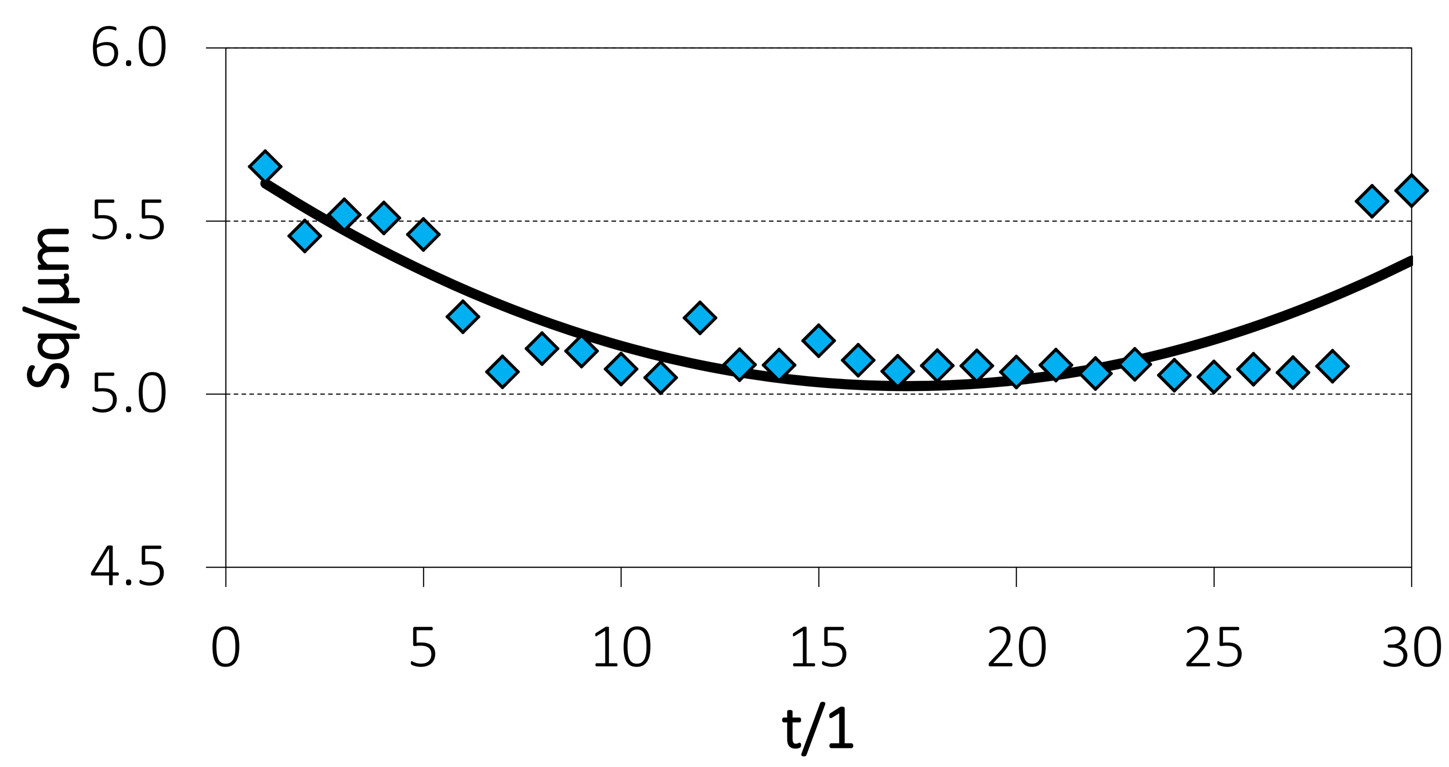


Figure 3. Graph of the experimental distribution of the *Sq* parameter (lozenges) and least squares regression model (line).

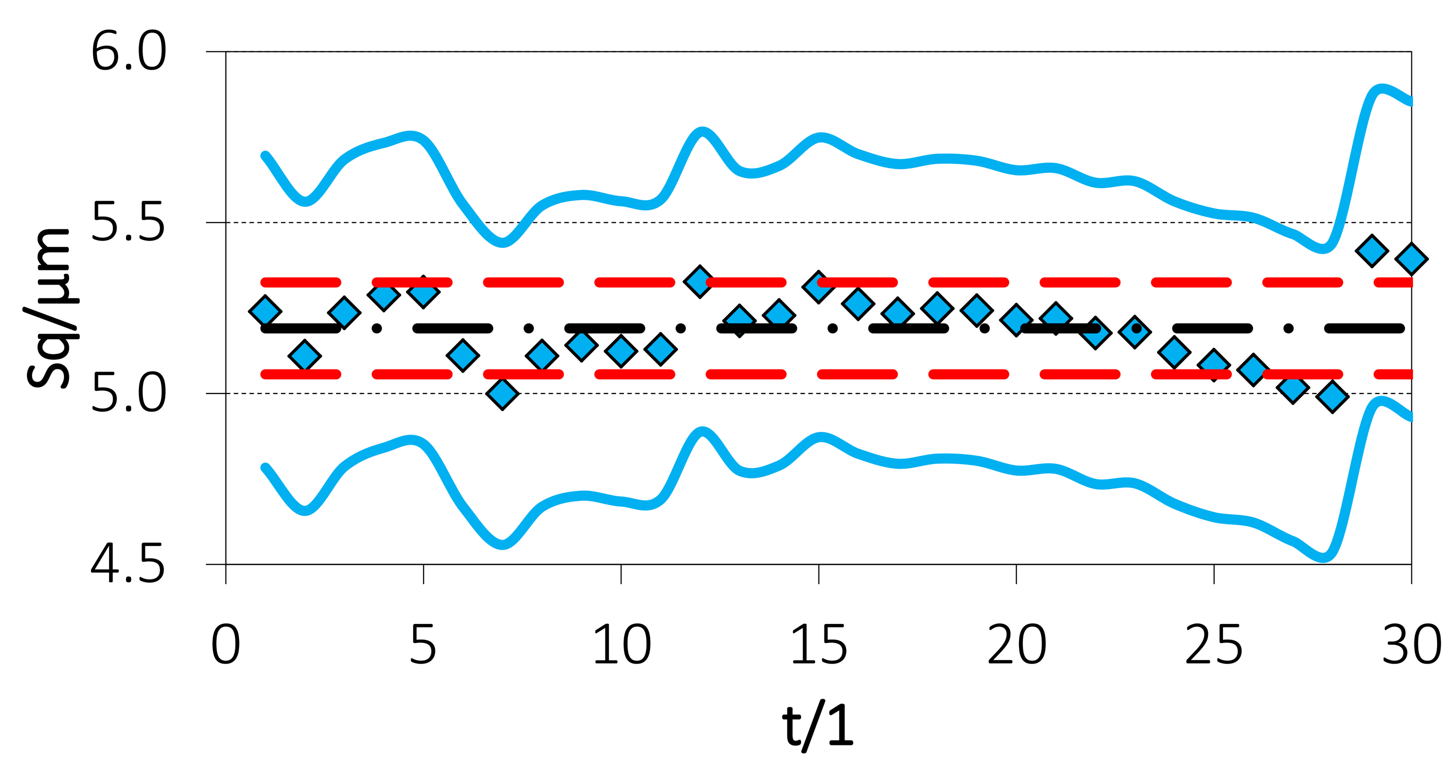


Figure 4. Graph of the experimental distribution of the *Sq* parameter after the correction (lozenges) and reference value (dotted-dashed straight line in the middle). The limits related to the expanded uncertainty are also indicated for the reference (dashed red lines) and for the corrected experimental distribution (external blue lines).

Conclusions

A statistical analysis has been outlined based on the correction of systematic behaviours in the experimental data distributions and which can be effective for an accurate evaluation of the measuring uncertainty.

Results show that agreement within single digit micrometre (dimensional measurements) and tenths of micrometre (surface parameters measurements) can be achieved with the proposed methodology.

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